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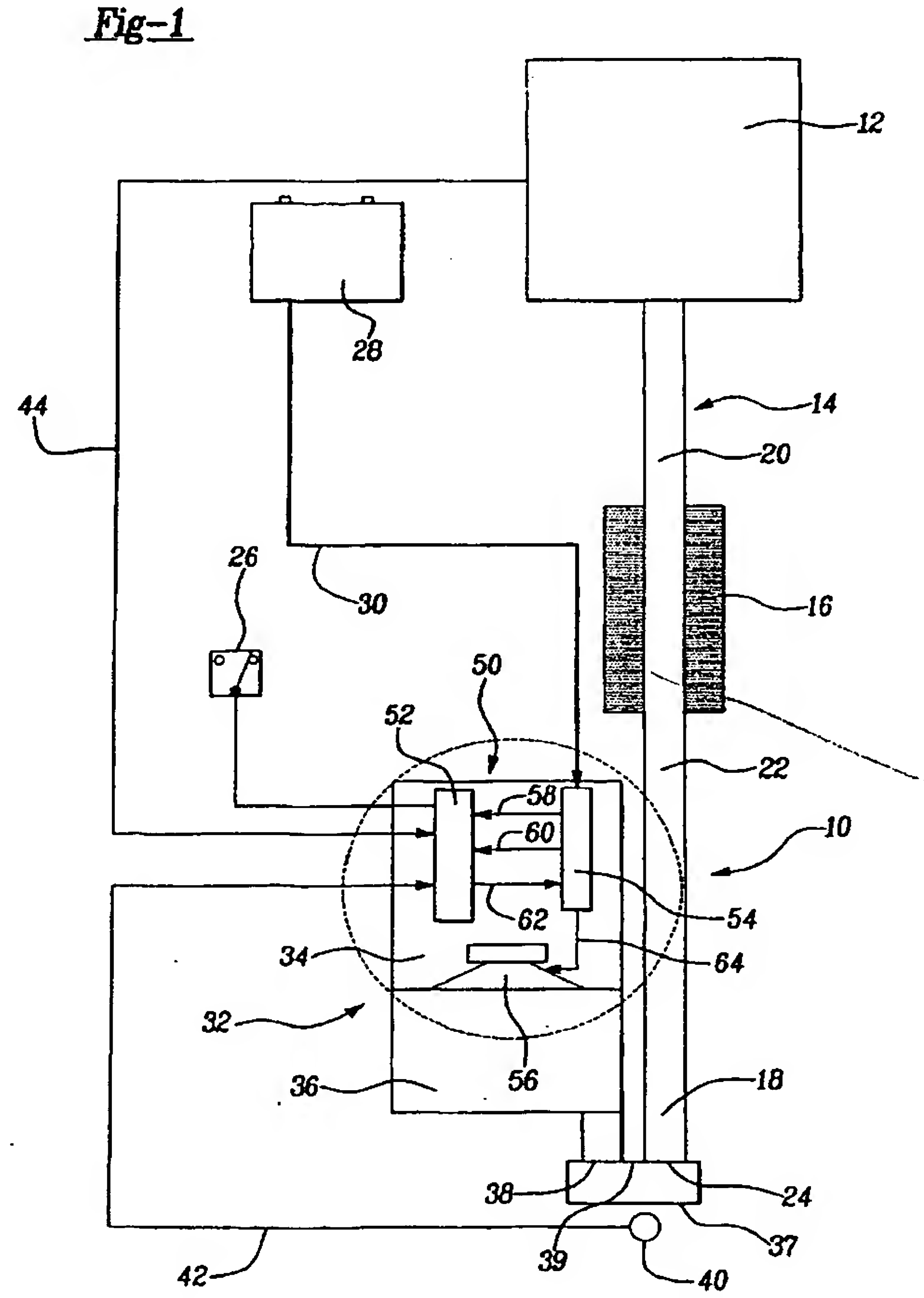
(54) Active noise conditioning system

(57) An active muffler system (10) for altering acoustic noise generated by a vehicle engine (12) at the exhaust output (14, 18) has an electronic circuitry (34) for generating an electrical noise alteration signal. An electrical-to-acoustic transducer (56) outputs an acoustic noise alteration signal in response to the electrical noise alteration signal. A switching element 26 is actuatable by the vehicle operator to selectively adjust the operation of the electronic circuitry (34).

Fig-1



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EUROPEAN SEARCH REPORT

Application Number
EP 02 02 8396

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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Y	US 4 862 506 A (LANDGARTEN HARRIS B ET AL) 29 August 1989 (1989-08-29) * abstract * ---	6	
A	US 5 336 856 A (KRIDER JAMES K ET AL) 9 August 1994 (1994-08-09) -----		TECHNICAL FIELDS SEARCHED (Int.Cl.7) G10K

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	19 March 2003	de Heering, Ph.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 02 02 8396

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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19-03-2003

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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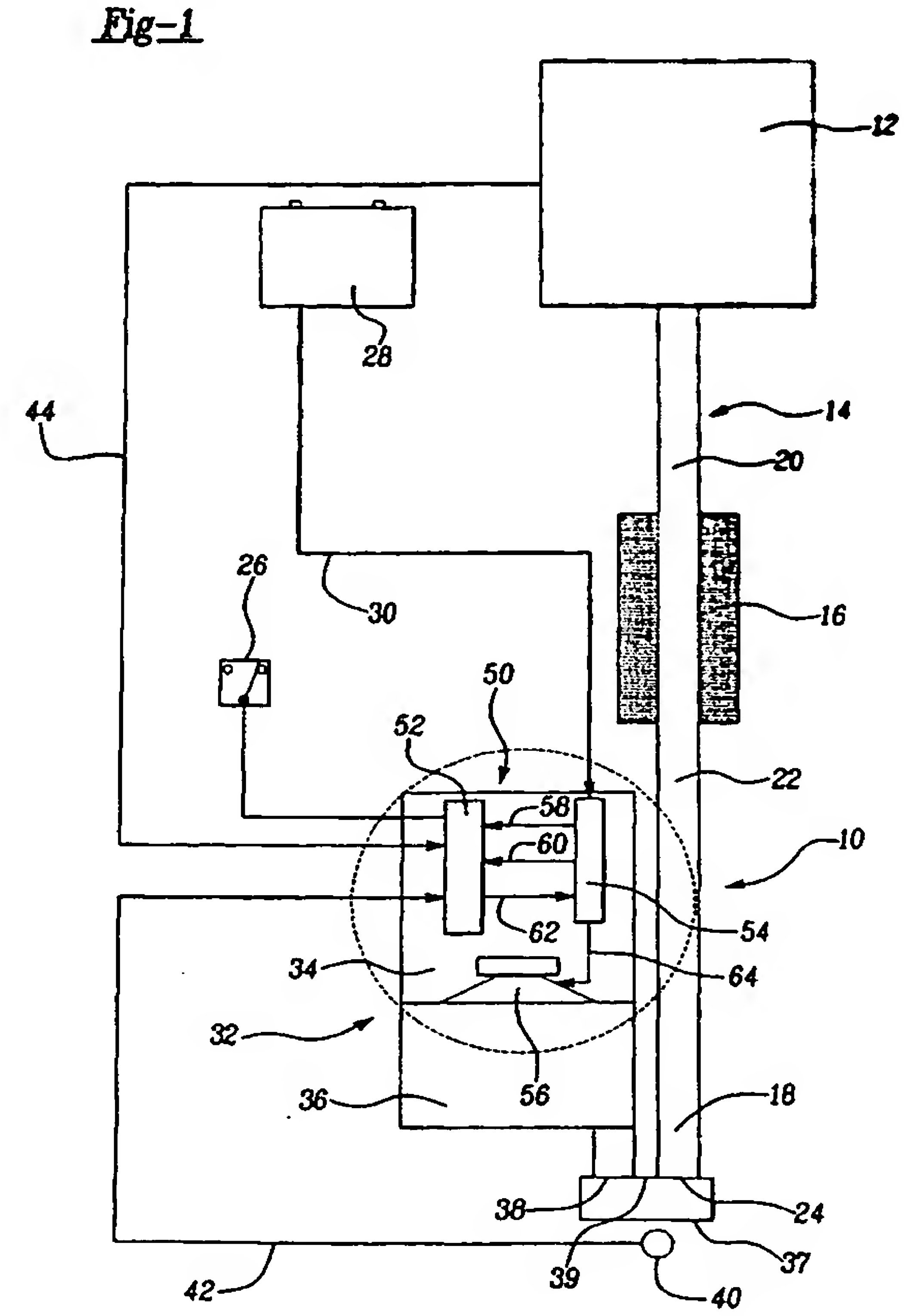
(54) **Active noise conditioning system**

(57) An active muffler system (10) for altering acoustic noise generated by a vehicle engine (12) at the exhaust output (14, 18) has an electronic circuitry (34) for generating an electrical noise alteration signal. An electrical-to-acoustic transducer (56) outputs an acoustic noise alteration signal in response to the electrical noise alteration signal. A switching element 26 is actuatable by the vehicle operator to selectively adjust the operation of the electronic circuitry (34).

Fig-1



EP 1 293 647 A2

Description

BACKGROUND OF THE INVENTION

1. Technical Field

[0001] This invention generally relates to an active noise conditioning system. More particularly, the present invention relates to an active noise cancellation muffler system employing feedback to control the output of the system.

2. Discussion

[0002] The application of active noise cancellation (ANC) technology to eliminate various noise signals is generally known within the electronics art. ANC technology is currently used in a variety of applications including controlling noise in manufacturing processes, lowering the noise levels within cabins of propeller driven airplanes, and significantly reducing the noise levels emitted from exhaust systems of combustion engines. These systems typically operate by creating an anti-noise signal which is equal in amplitude and opposite in phase with the primary noise signal. In theory, when the primary noise signal and the anti-noise signal are acoustically combined, the two signals effectively cancel one another which significantly reduces the production of any sound. While at first glance these principles appear simple, the implementation of these systems has thus far been problematic. These problems have been further compounded when trying to integrate an active noise cancellation muffler system into the constraints of a production vehicle or production automobile exhaust system.

[0003] ANC muffler systems have the advantage of eliminating the conventional muffler from the exhaust system which in turn eliminates unwanted exhaust back pressure. A low restriction passive exhaust system is sometimes used with the ANC muffler system to attenuate high frequency noise, which is outside the ANC muffler system's frequency band of operation. The passive exhaust system also serves to minimize the effects of back pressure on the engine. This decrease in back pressure results in a substantial increase in engine horsepower.

[0004] The prior art ANC muffler systems are typically comprised of a processor based control unit, an amplifier, a DC to DC step-up power supply for powering the amplifier, a housing placed in line with the exhaust system containing one or more speakers, a microphone and a speed sensor for providing feedback to the controller, and a low restriction passive exhaust system. The controller of an ANC muffler system receives feedback from the microphone and speed sensor to determined the frequency, amplitude, and phase content of the exhaust system's noise signal. The controller generates the 180 degree out-of-phase anti-noise signal in response to the feedback. This anti-noise signal is amplified and broadcast through the outlet of the speaker enclosure. The outlet of the speaker enclosure and the exhaust tailpipe are collocated such that the acoustic coupling between the exhaust noise and the anti-noise results in a significant reduction of the total exhaust noise level. This process is continually updated to track and minimize the exhaust noise output measured by the microphone.

[0005] The power source for these ANC muffler systems is the vehicle's electrical system. As such, the maximum power produced by the system is limited to the power provided by the vehicle's electrical system. The critical requirement for an ANC muffler system, particularly for an automobile, is that the system must be capable of generating sound pressure levels equal to that of the residual exhaust noise. This must be accomplished using the vehicle's electrical system as the primary source of power.

[0006] The ANC muffler systems known within the art have several problems. First, most of these systems use a conventional Class-AB audio amplifier for generating the amplified anti-noise signal. These Class-AB amplifiers typically operate at an efficiency level of approximately 50%. Therefore, more input power is required to generate an acceptable operating power level. Second, the prior art ANC muffler systems have high voltage requirements because these systems employ speakers with higher impedance voice coils; typically two (2.0) Ohms, which draw less current. Therefore, these systems require a power supply with a step-up DC-DC converter to generate sufficient voltage to power the amplifier and speakers. These power supplies are only about 80% efficient, and therefore further reduce the electrical efficiency of the ANC muffler system. This higher power requirement also causes dissipation of additional energy, in the form of heat, which must be removed from the system to keep it operationally stable. Therefore, these systems require additional heat sinking to effectively remove this excess heat. Finally, these systems produce an analog anti-noise signal which is subject to electrical interference or noise created from within the vehicle. This in turn can cause contamination of the anti-noise signal and affect the overall ability of the ANC muffler system to cancel the exhaust noise.

[0007] Additionally, the inefficiency and size of the known ANC muffler systems and their accompanying electronics require an electronics enclosure, separate from the speaker housing, which must be mounted on the vehicle in a location which is not sensitive to the heat generated by the electronics therein. As such, the interior compartments of the vehicle or locations in the vicinity thereof are undesirable for accommodating the electronics enclosure due to the

amount of heat generated by the electronics. Thus, any electronics enclosure placed underneath the vehicle must be able to withstand extreme environmental conditions. Such a requirement also causes the electronics enclosure to be significantly more expensive. Finally, these previous systems use a separate speaker housing which is in line with the vehicle's exhaust system. Such a design exposes the speakers to the heat, moisture and contaminants contained within the engine's exhaust. Further, designing a more expensive housing and speakers which are unaffected by these conditions only adds to the total cost of implementing an ANC muffler system. Accordingly, these limitations have prevented the widespread use of ANC muffler systems in mass produced vehicles.

[0008] In view of the limitations associated with the prior art, it would be desirable to provide an active noise cancellation muffler system which is significantly more efficient than those known within the prior art. It would also be desirable to provide an ANC muffler system which can optionally eliminate the need for an additional power supply to step-up and/or regulate the power received from the vehicle's battery just to power the amplifier. Furthermore, it is desirable to provide an ANC muffler system in which the signal processing electronics, amplifier, and wave generator are contained within a single enclosure. In addition, it would be desirable for such an enclosure to also provide heat sinking capabilities to the entire system. Finally, it is an object of the present invention to provide an enclosure which is not limited to a specific shape, and can be mounted in a variety of locations within or underneath the vehicle.

SUMMARY OF THE INVENTION

[0009] Pursuant to the present invention, a self-contained and highly efficient active noise cancellation muffler system is disclosed. The reduced power requirements and lower amount of heat dissipated by the present system allow all of the components to be integrated into a single enclosure. The result is numerous improvements over conventional ANC muffler systems, as well as an improved method for reducing exhaust noise.

[0010] In accordance with the teachings of the present invention, an active noise cancellation system is provided. The active noise cancellation system may be used with either a single channel or dual channel exhaust system. A controller receives an exhaust noise signal, along with various other feedback signals for producing an anti-noise signal in response to these input signals. An amplifier is provided for receiving and amplifying the anti-noise signal. A wave generator receives the amplified anti-noise signal and produces an audio anti-noise signal. The output of the wave generator is collocated with the exhaust pipe outlet of the exhaust system, where the audio anti-noise signal and the exhaust noise are acoustically coupled, which significantly reduces the exhaust noise. Also in accordance with the teachings of this invention, a method is provided for calculating the anti-noise signal and controlling the output of the amplifier using various feedback signals.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Additional objects, advantages, and features of the present invention will become apparent from the following description and appended claims, taken in conjunction with the accompanying drawings in which:

FIG. 1 is a block diagram schematic of the active noise cancellation muffler system used with a single channel exhaust system in accordance with a preferred embodiment of the present invention;

FIG. 2 is a block diagram schematic of the system in conjunction with a dual channel exhaust system in accordance with a preferred embodiment of the present invention;

FIG. 3 is an enlarged block diagram of the electronics associated with the single channel exhaust system in accordance with a preferred embodiment of the present invention;

FIG. 4 is an enlarged block diagram of the electronics used with a dual channel exhaust system in accordance with a preferred embodiment of the present invention;

FIG. 5 is a block diagram showing the signal flow of the system and the controller's electrical components in accordance with a preferred embodiment of the present invention;

FIG. 6 is a graphical representation of the amplifier peak output as a function of the battery dependent controller output in accordance with a preferred embodiment of the present invention; and

FIG. 7 shows the coupling box used in conjunction with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] The following description of the preferred embodiments is merely exemplary in nature and is in no way intended to limit the Invention, its applications or uses.

[0013] The present invention is directed to a device and method for reducing the exhaust noise of a combustion engine. The primary application of an active noise cancellation (ANC) muffler system is to provide a muffler system which eliminates exhaust noise without creating back pressure within the exhaust system. The benefit of such a system

provides additional power to the combustion engine. The invention disclosed herein is not dependent upon an additional power supply for driving the amplifier, and especially a power supply requiring a step-up DC-DC converter. These improvements eliminate the need for additional heat sinking, and further allow all of the electrical components to be housed within a single enclosure. A unique feature of this invention is that rather than using an additional power supply to control the system's output, the amplifier output is adjusted by the controller in response to a battery feedback signal and/or a microphone feedback signal. This feature assists in further boosting the efficiency of the total system.

[0014] Referring now to FIG. 1, the various components of the active noise cancellation muffler system for use with a single channel exhaust system are disclosed. However, it should be noted that the system of the present invention can also be used with a multichannel system. As illustrated, muffler system 10 is used in conjunction with a combustion engine 12 having an exhaust pipe 14 connected thereto. A passive exhaust system 16 is shown connected between exhaust pipe 14 and tailpipe 18. An exhaust noise signal flowing through pre-attenuation portion 20 contains the full range of harmonic frequencies generated by the engine 12. However, exhaust noise signal passing through post-attenuation portion 22 contains little or no high frequency harmonics because these high frequencies have been removed by the passive exhaust system 16. The exhaust noise signal continues through tailpipe 18 and eventually exits through outlet 24.

[0015] ANC muffler system 10 is powered by the vehicle's electrical system 28 through a supply line 30. The vehicle's electrical system 28 is typically a 12V DC power source. One of the key components of muffler system 10 is enclosure 32, which is preferably constructed from cast aluminum or a substitute formable metal which is capable of dissipating heat. However, enclosure 32 is not limited to cast aluminum or formable metal, but also may be constructed from various injection molded plastics or resin, having a heat sink molded therein. Accordingly, enclosure 32 may serve a dual purpose of housing all of the electronics and functioning as a heat sink for the electronics. While many of the advantages of enclosure 32 will be described in more detail herein, a particularly unique feature is that enclosure 32 it is not limited to a particular shape. More particularly, enclosure 32 can be formed into almost any shape, thus allowing the enclosure 32 to be located almost anywhere on the vehicle.

[0016] Enclosure 32 includes an electronics portion 34 and a tuned acoustic chamber 36. The anti-noise signal which is produced within tuned acoustic chamber 36 is emitted from the enclosure outlet 38. As seen in FIG. 1, the exhaust noise signal emitted from the tailpipe outlet 24 and the anti-noise signal emitted from the enclosure outlet 38 are acoustically coupled at the location of those outlets, which serves to effectively cancel the exhaust noise signal.

[0017] As seen in FIGS. 1 and 7, the acoustic coupling of the exhaust noise signal and the anti-noise signal may be enhanced by a coupling box 37. As disclosed, the tailpipe outlet 24 and the enclosure outlet 38 feed through openings formed in the rear wall 39 of the coupling box 37. The end portion of coupling box 37 which is opposed to the rear wall 39 is open to the atmosphere, allowing the acoustically coupled signals to freely escape.

[0018] Any residual noise which remains from the acoustic coupling of these two signals is received by a microphone 40, positioned in the vicinity of the outlets 24, 38. Microphone 40 may also be positioned within the coupling box 37. Preferably, microphone 40 produces an analog exhaust noise feedback signal 42 which is transmitted back to a controller 52. However, a digital microphone or other similar transducer which produces a digital signal could be substituted for microphone 40. Such a device would have the advantage of shielding the digital feedback signal from outside noise. The exhaust noise feedback signal 42 represents residual error between the exhaust noise signal and the anti-noise signal.

[0019] Exhaust system 10 also utilizes a synchronization signal 44 produced by combustion engine 12. The synchronization signal represents the real time rotational speed or frequency of the combustion engine 12. This signal assists the ANC muffler system 10 in predicting the range of frequencies contained within the exhaust noise signal emitted from the tailpipe outlet 24. The advantages of employing synchronization signal 44 will become apparent as it is discussed in further detail below.

[0020] The electronics portion 34 of enclosure 32 houses the signal processing electronics 50 of the muffler system 10. More particularly, the signal processing electronics 50 include a controller 52 which receives the exhaust noise feedback signal 42 and the synchronization signal 44 as input signals. Controller 52 is coupled to an amplifier 54 which produces an amplified anti-noise signal to a wave generator 56 via amplifier output 64. Amplifier 54 is powered by the vehicle's electrical system 28 via power line 30. As disclosed, amplifier 54 is also capable of providing a 5V DC power source 58 to the electronics contained within controller 52. The power received on line 30 is passed through amplifier 54 as an additional input or feedback signal to controller 52. This battery feedback signal 60 can be monitored by the electronics within controller 52. The battery feedback signal 60 can be used by controller 52 to continually adjust the output of the amplifier 54. This is one of several features which are unique to this invention. One skilled in the art will appreciate that during typical operating conditions, the voltage output by the vehicle's electrical system 28 will vary significantly from 12 volts. This variation is caused both by the vehicle's alternator providing excess electricity, and other electrical systems within the vehicle drawing electricity. As such, controller 52 is capable of monitoring this fluctuation in the output voltage from the vehicle's electrical system 28, and is further capable of adjusting the system's output in response to these constant changes.

[0021] In response to the microphone feedback signal 42, the controller 52 calculates and generates an anti-noise signal which is presented on control output 62 and provided to the amplifier 54. The amplifier 54 provides additional gain to the anti-noise signal thereby producing an amplified anti-noise signal on amplifier output 64. This output is coupled to a wave generator 56 for producing an audio anti-noise signal into tuned acoustic chamber 36. One skilled in the art will appreciate that while at least one speaker driven by a voice coil is preferred, wave generator 56 can also include, but is not limited to, a piezoelectric device, or a piezoceramic device. A preferred speaker for wave generator 56 is a 0.5 Ohm speaker which draws more electrical current, but utilizes a lower voltage to generate the requisite power level. Such an implementation allows the power supply, necessary in the prior art systems, to be eliminated in the present invention. This is possible because the 0.5 Ohm speaker eliminates the need for a stepped-up voltage. This audio anti-noise signal produced by wave generator 56 is emitted from enclosure outlet 38 and is acoustically coupled with the exhaust noise signal emitted from outlet 24 as described above. In view of this description, one skilled in the art will appreciate that controller 52 is constantly receiving a real-time, updated, time variant error signal, or microphone feedback signal 42 produced by microphone 40. Accordingly, controller 52 is capable of updating the audio anti-noise signal in real time for effectively eliminating the audible exhaust noise level emitted from the exhaust system.

[0022] Referring now to FIG. 2, the active noise cancellation muffler system is disclosed for use in conjunction with a dual channel exhaust system. In operation, dual channel ANC exhaust system 11 operates in a substantially similar manner, that includes substantially the same components as the single channel ANC muffler system 10 of FIG. 1. As disclosed, dual channel ANC muffler system 11 includes a combustion engine 12' connected to a pair of exhaust pipes 14a', 14b'. A two channel passive exhaust system 16a', 16b' is also provided, and differs only in that it is capable of simultaneously attenuating the high frequency harmonic components received from the pair of exhaust pipes 14a', 14b'. As previously discussed, the exhaust noise signal flowing through pre-attenuation portions 20a', 20b' contains the full range of harmonic frequencies generated by the engine 12'. The exhaust noise signal passing through the post-attenuation portions 22a', 22b' contains little or no high frequency components, as they have been removed by the dual channel passive exhaust system 16a', 16b'. The exhaust noise signal continues through a pair of tailpipes 18a', 18b' and is emitted from a pair of tailpipe outlets 24a', 24b'.

[0023] In this embodiment, enclosure 32' along with its components are substantially similar to enclosure 32 described above. Additionally, the signal processing electronics 50' disclosed in this alternate embodiment, are substantially similar to those disclosed by signal processing electronics 50, with only the addition of duplicate components and outputs to accommodate the second channel. As clearly see in FIG. 2, controller 52' receives synchronization signal 44' along with microphone feedback signal 42' produced by microphone 40'. However, controller 52' also receives a second microphone feedback signal 90 produced by second microphone 88. In addition to producing a first control output 62' to first amplifier 54', controller 52' additionally produces a second control output 66 which is provided to a second amplifier 82. The output from amplifier 82 is provided to a second wave generator 86 via amplifier output 84.

[0024] The significant difference between the single channel ANC muffler system 10 of FIG. 1 and the dual channel ANC muffler system 11 of FIG. 2 is the addition of a second enclosure 72. As disclosed, enclosure 72 is substantially similar to enclosure 32', and includes an electronics portion 74 and a tuned acoustic chamber 76. The anti-noise signal generated by enclosure 72 is emitted from enclosure outlet 78. Enclosure 72 also includes signal processing electronics 80 for use with the second channel. Signal processing electronics 80 include slightly fewer components than signal processing electronics 50'. As disclosed, the dual channel muffler system 11 requires only a single controller 52'. As such, signal processing electronics 80 require only a second amplifier 82 and a second wave generator 86 driven by second amplifier output 84.

[0025] Referring now to FIGS. 3 and 4, the subtle differences between signal processing electronics 50 and 50' can be seen with more particular detail. FIG. 3 discloses the signal processing electronics 50 used in conjunction with the single channel muffler system 10. FIG. 4 discloses the signal processing electronics 50' used in conjunction with the dual channel muffler system 11. When viewing FIG. 4 in detail, one skilled in the art will appreciate that controller 52' includes the same inputs as controller 52, with the addition of second microphone feedback input 90 as well as the second controller output 66. In the embodiment disclosed by FIG. 4, controller 52' is capable of monitoring the feedback from each microphone 40', 88 associated with each tailpipe outlet 24a', 24b' in addition to monitoring the battery feedback signal 60' and synchronization signal 44'. Controller 52' is also capable of controlling a second amplifier 82 and wave generator 86 combination. One skilled in the art will readily appreciate that a single controller is capable of monitoring the various feedback signals and producing individual anti-noise signals for either a single channel or dual channel ANC exhaust system. It should also be particularly noted that due to the high efficiency of the present invention, all of the electronics 50, including the amplifier 54, can be contained within the electronics portion 34 of the enclosure 32 and/or 72. The low amount of heat dissipated by the amplifier 54 and the absence of an additional power supply also make such a self-contained system possible. Alternatively, the efficiency of the present invention can accommodate a power supply (not shown) and still provide a system in which all of the electronics are contained within a single enclosure 32, 72. In either situation, any necessary heat sinking can be accommodated by the enclosure 32, 72 itself.

[0026] Referring now to FIG. 5, the signal flow of the feedback signals and output signals of the active noise can-

cellation muffler system is presented. According to this preferred embodiment, signal processing electronics 50 include the components described above. More particularly, the components representing controller 52 are disclosed via a block diagram in FIG. 5. As illustrated, controller 52 includes a digital signal processor 100 which is connected to and receives input from a multichannel analog-to-digital converter 102, and synchronization signal one-shot converter 104. A representative component for digital signal processor 100 is the DSP manufactured by Analog Devices, Model No. ADSP2181BS-115. An exemplary component for the multichannel A/D converter 102 is Model No. TLC2543, manufactured by Texas Instruments, and an exemplary component for one-shot 104 is Model No. 74HC221 manufactured by National Semiconductor. More particularly, A/D converter 102 receives multiple analog input signals and produces multiple digital output signals. As disclosed, A/D converter 102 receives an analog feedback signal 42 from microphone 40, an analog feedback signal 60 from the vehicle's electrical system 28, and optionally a second analog feedback signal 90 from microphone 88 (not shown). These analog signals 42, 60, and 90 are converted into digital microphone feedback signal 106, digital battery feedback signal 107, and a digital second microphone feedback signal (not shown) respectively. In a similar fashion, one-shot converter 104 receives an analog synchronization signal 44 from engine 12 and converts this analog signal to a digital synchronization signal 108. Alternatively, a digital synchronization signal 108 could be received directly from the vehicle's electrical control system. The frequency of digital synchronization signal 108 represents the rotational frequency of the combustion engine 12, and thus represents the harmonic frequency components contained in the exhaust noise signal. Supplying a synchronization signal to controller 52 has the advantage of providing advanced frequency information to the control system algorithm 200. Digital signals 106, 107 and 108 are provided as inputs to digital signal processor 100 for further processing by the control algorithm 200.

[0027] Digital signal processor 100 is responsible for monitoring the various inputs of the system, and producing an anti-noise signal in digital format. The digital anti-noise signal 110, produced by the digital signal processor 100 is provided to a digital-to-pulse width modulation converter (D/PWM) 112. D/PWM converter 112 transforms the digital anti-noise signal 110 into a pulse width modulation signal 62 which is provided to amplifier 54. A preferred D/PWM converter 112 is that manufactured by Harris Semi-Conductor, Model No. CD68HC68. As disclosed, amplifier 54 (and amplifier 82, not shown in FIG. 5) is a Class-D amplifier which is designed to receive a digital pulse width modulation signal as its input. Amplifier 54 has several advantages over amplifiers used in previous systems. The prior art systems typically employ a Class-AB amplifier to reproduce the analog anti-noise signal. The use of such an analog amplifier subjects the anti-noise signal to additional interference or corruption. In addition, most Class-AB amplifiers are only about 50% efficient. Thus, this amplifier required additional power as well as additional heat sinking to dissipate the excessive heat generated.

[0028] The amplifier 54 of the present invention overcomes both of these significant problems. First, Class-D amplifiers are designed to receive a digital input signal. As such, the digital anti-noise signal 110 is almost completely isolated from external noise which could potentially corrupt the signal quality. Secondly, Class-D amplifiers using high current MOSFET technology operate at efficiencies above 90%. A representative Class-D amplifier chip for use in accordance with this invention is EL7661, manufactured by Elantic. Additionally, the significantly higher efficiency of such a Class-D amplifier requires less power and less heat sinking. Further, the combination of a Class-D amplifier and a low impedance speaker does not require a separate power supply. Thus, the Class-D amplifier can be powered directly from the vehicle's electrical system 28. Because of the smaller heat sinking requirements, the system of the present invention can use the enclosure 32 as its only source for heat sinking.

[0029] With continued reference to FIG. 5, the algorithm 200 implemented by DSP 100 is disclosed with more particular detail. A suitable control algorithm is that disclosed by U.S. Patent No. 5,469,087 to Eatwell, issued on November 21, 1995, which is expressly incorporated herein by reference. However, a variation on the Eatwell control algorithm which comprises the control algorithm 200 of the present invention implemented by DSP 100 is provided below. One skilled in the art will appreciate that many variations of the control algorithm 200 can be implemented for controlling the ANC muffler system presented herein.

[0030] Generally, algorithm 200 receives the digital feedback signals produced by the synchronization signal one-shot converter 104 and the multichannel microphone feedback signal and battery feedback signal A/D converter 102. From these inputs, the algorithm calculates the anti-noise signal, including its phase and frequency components, as shown in block 210. The algorithm receives the battery feedback signal 60 in order to calculate the battery gain factor denoted K_{bat} at block 220. Upon combining the information produced by block 210 and block 220, the algorithm calculates an adjusted anti-noise signal at block 230. The gain of this anti-noise signal is adjusted in response to the continually varying amount of power produced by the vehicle's electrical system 28. Alternatively, the gain of the anti-noise signal may be adjusted in response to the microphone feedback signal 42. The continually updated digital anti-noise signal is represented by block 240. As discussed previously, the output of DSP 100 is a purely digital signal 110 which is provided to D/PWM converter 112 and transformed into a pulse width modulation signal 62. This PWM signal 62 is fed directly into the input of amplifier 54. In operation, the active noise cancellation muffler system, and more particularly the algorithm 200 of controller 52, performs these operations on a continual and real time basis. Accordingly, the benefits of this improved system are apparent when compared to previous systems known within the prior art.

[0031] More specifically, the gain of the amplifier 54 is dependent upon the supply voltage V from the vehicle's electrical system 28. The controller output 110 must be adjusted to account for any variation in this voltage V, otherwise, the anti-noise signal will not have the correct power level required to cancel the exhaust noise,

[0032] As is known in a feedback control system, the feedback gain is set to give a high degree of attenuation without causing instability. Since the amplifier 54 is part of the feedback loop, any change in the amplifier gain should be accounted for if optimal performance is to be maintained. For example, if the amplifier gain becomes much higher than the optimum gain, the system may become unstable. If the amplifier gain becomes much lower than the optimum gain, poor performance will result.

[0033] The same is true of an adaptive control system for an active noise conditioning system. The adaptation step size performs the same role as the feedback gain (see Eatwell, "Tonal Noise Control Using Harmonic Filters," Proceedings of Active 95, Newport Beach, CA, for example). Hence, it is desirable that the system loop gain be made insensitive to supply voltage variations, or that the control algorithm be modified to account for the variations.

[0034] The system transfer function is the response of the loop from the controller output 62 to the controller input 42 at a given frequency. In one embodiment of the present invention, a variable gain G is inserted at some point in this loop. The gain should be selected according to the following criteria.

[0035] During a calibration phase, the gain is set to G_0 and the voltage supplied to the amplifier 54 is V_0. The transfer function $A(\omega, G, V)$ depends upon the frequency ω, the current gain G and the current voltage V. This is related to the transfer function at calibration by

$$A(\varpi,G,V) = \frac{G}{G_0} A(\varpi,G_0,V) = \frac{V}{V_0}\frac{G}{G_0} A(\varpi,G_0,V_0)$$

From this expression it is clear that the transfer function will be independent of the voltage provided that

$$\frac{V}{V_0}\frac{G}{G_0} = 1$$

or

$$G = G_0 \frac{V_0}{V}$$

In other words, the gain should be chosen to be inversely proportional to the vehicle's electrical system 28 supply voltage V. This ensures that the control system response will be insensitive to variations in the supply voltage of the vehicle's electrical system 28. In these expressions, V_0/V is the same as K_{bat}.

[0036] Since the supply voltage of the vehicle's electrical system 28 may be continuously varying, it is necessary for the controller 52 to continuously monitor the supply voltage and continuously vary the gain of the anti-noise signal provided to the amplifier 54.

[0037] The gain can be applied at any point in the control loop. For example, it can be applied to the digitized microphone signal 106 or to the digital signal processor output signal 110. Alternatively, it can be applied as part of the output calculation 210. As an example of this, a modification in the Harmonic Filter algorithm U.S. Patent No. 5,469,087 will now be described. The disclosure of U.S. Patent No. 5,469,087 is expressly incorporated herein by reference.

[0038] In the Harmonic Filter algorithm the output harmonic amplitudes Y are updated at the nth iteration according to equation 12 of U.S. Patent No. 5,469,087, namely

$$Y_k^n = (1-\lambda)Y_k^{n-1} - \mu B(\varpi)R_k^{n-1}$$

where k is the harmonic number, μ the step size, $B(\omega)$ is related to the system transfer function and R is the harmonic transform of the residual microphone signal at this harmonic. In the control algorithm 200 of the present invention, this algorithm may be replaced by

Fig-1

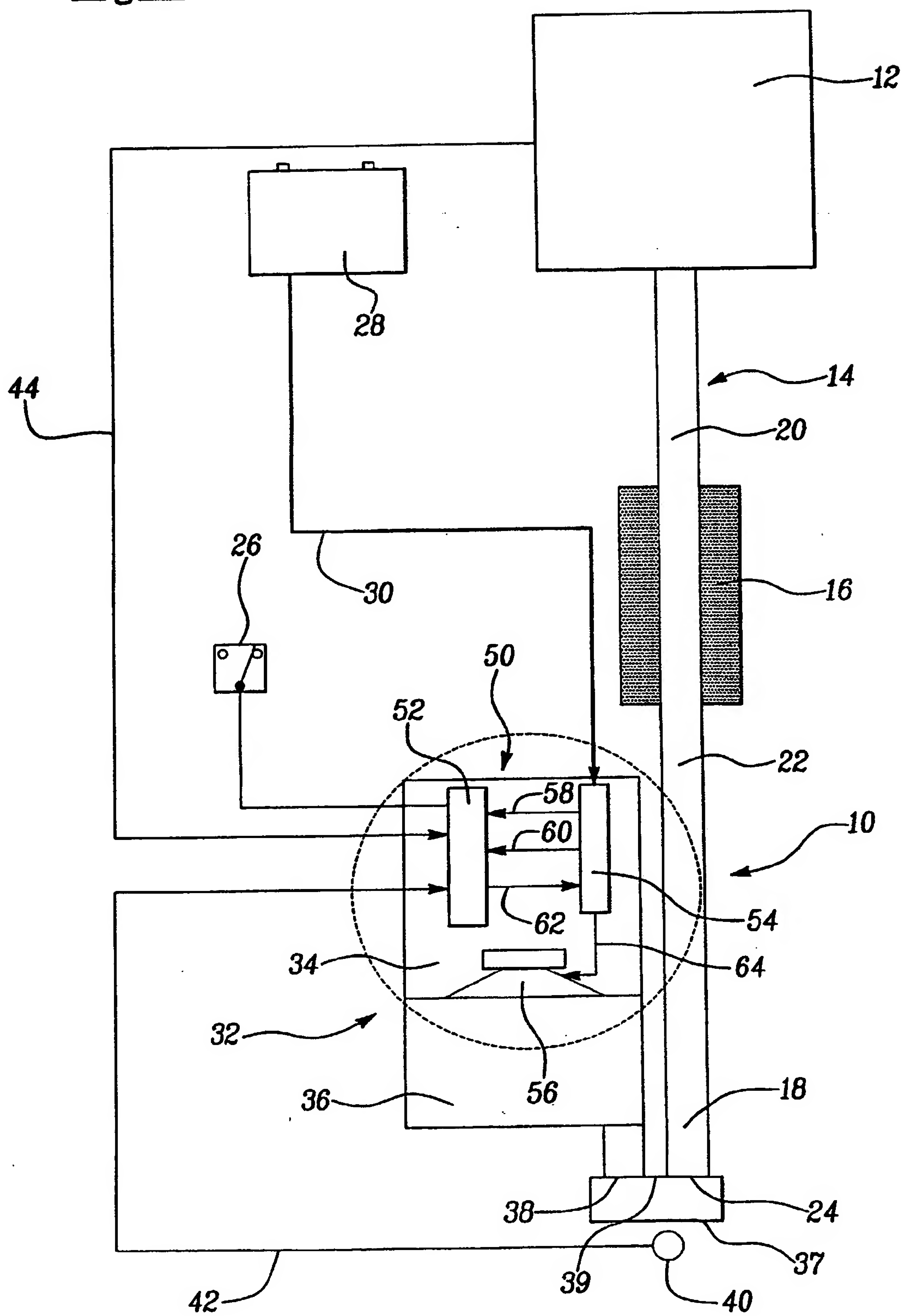
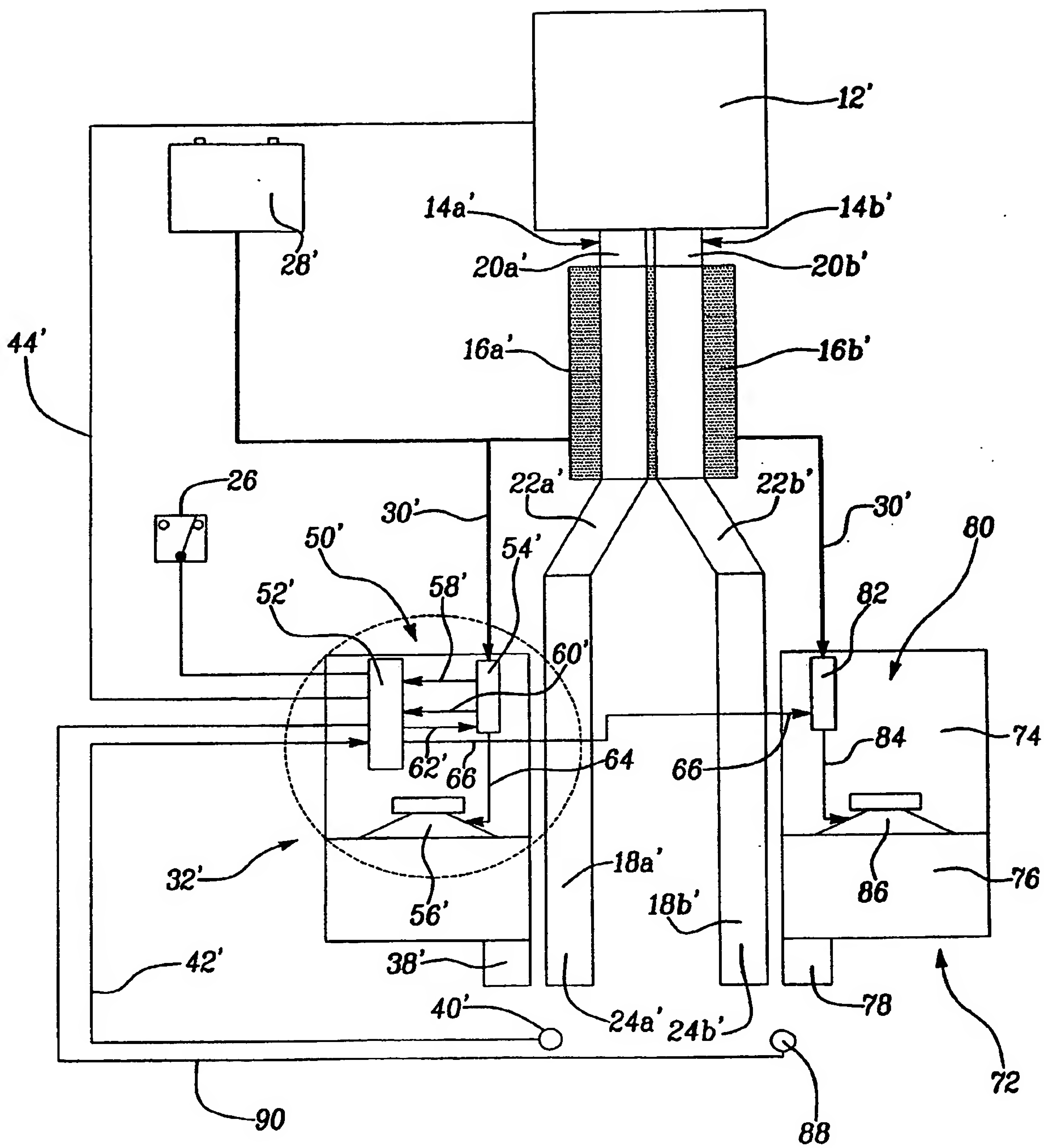

12
28
14
20
44
16
26
30
50
52
58
60
10
54
62
34
64
32
56
36
18
38
24
37
39
42
40

Fig-2


12'
14a'
14b'
20a'
20b'
28'
44'
16a'
16b'
26
22a'
22b'
30'
30'
50'
54'
80
52'
58'
82
60'
62'
66
64
66
84
74
32'
56'
18a'
18b'
86
76
42'
38'
40'
24a'
24b'
78
72
90
88

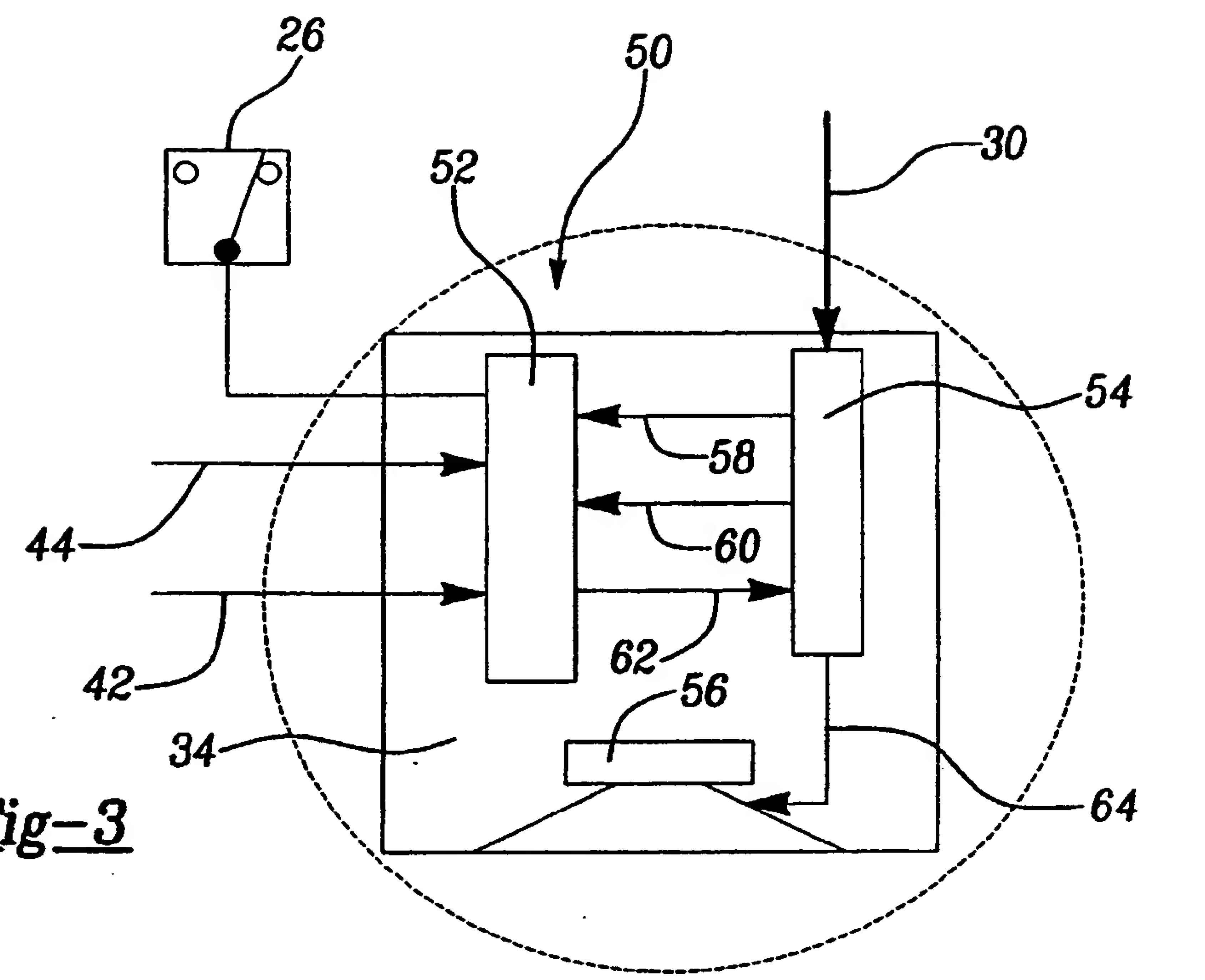

26
50
30
52
54
58
60
44
42
62
56
34
64

Fig-3

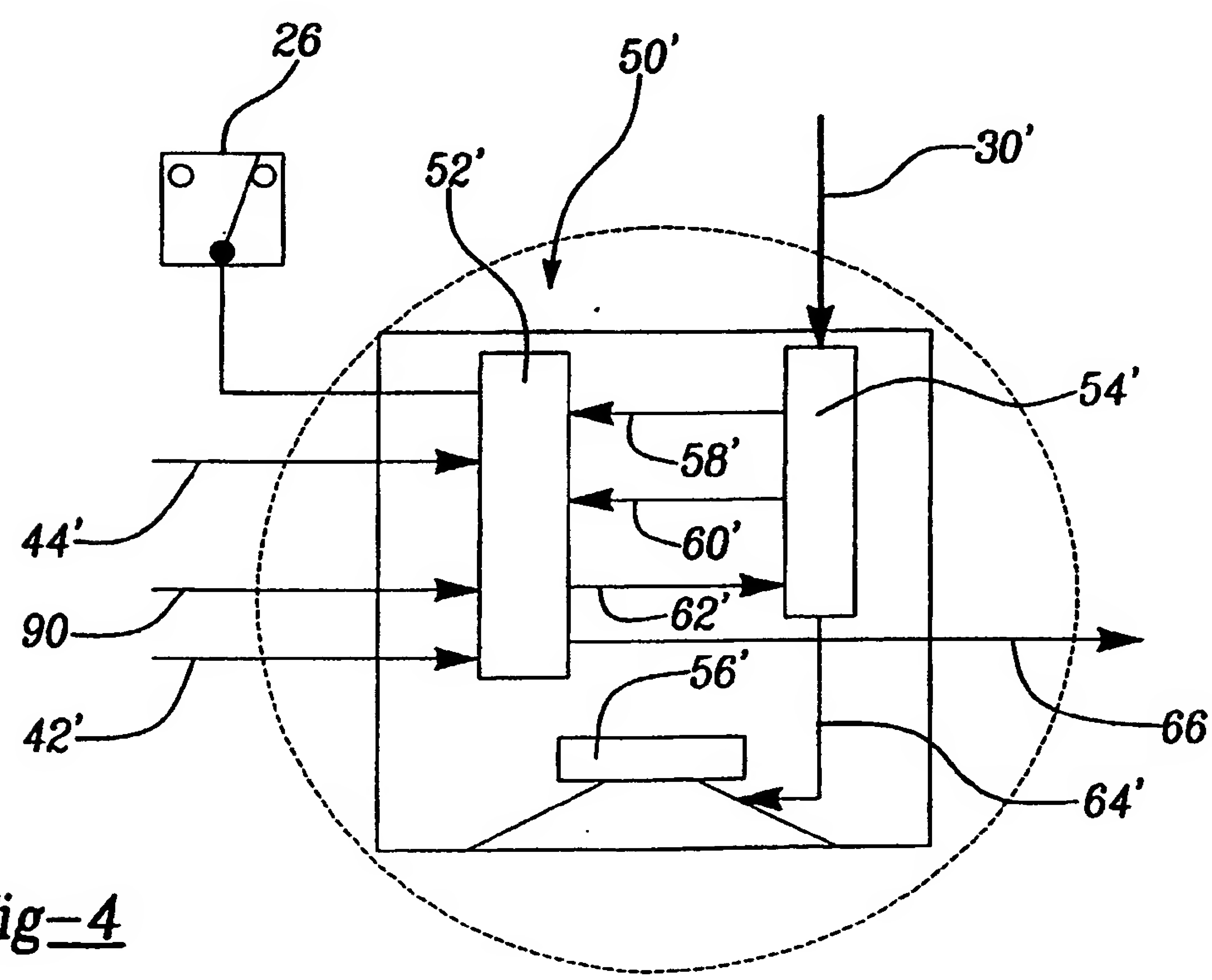

26
50'
30'
52'
54'
58'
60'
44'
90
62'
42'
56'
66
64'

Fig-4

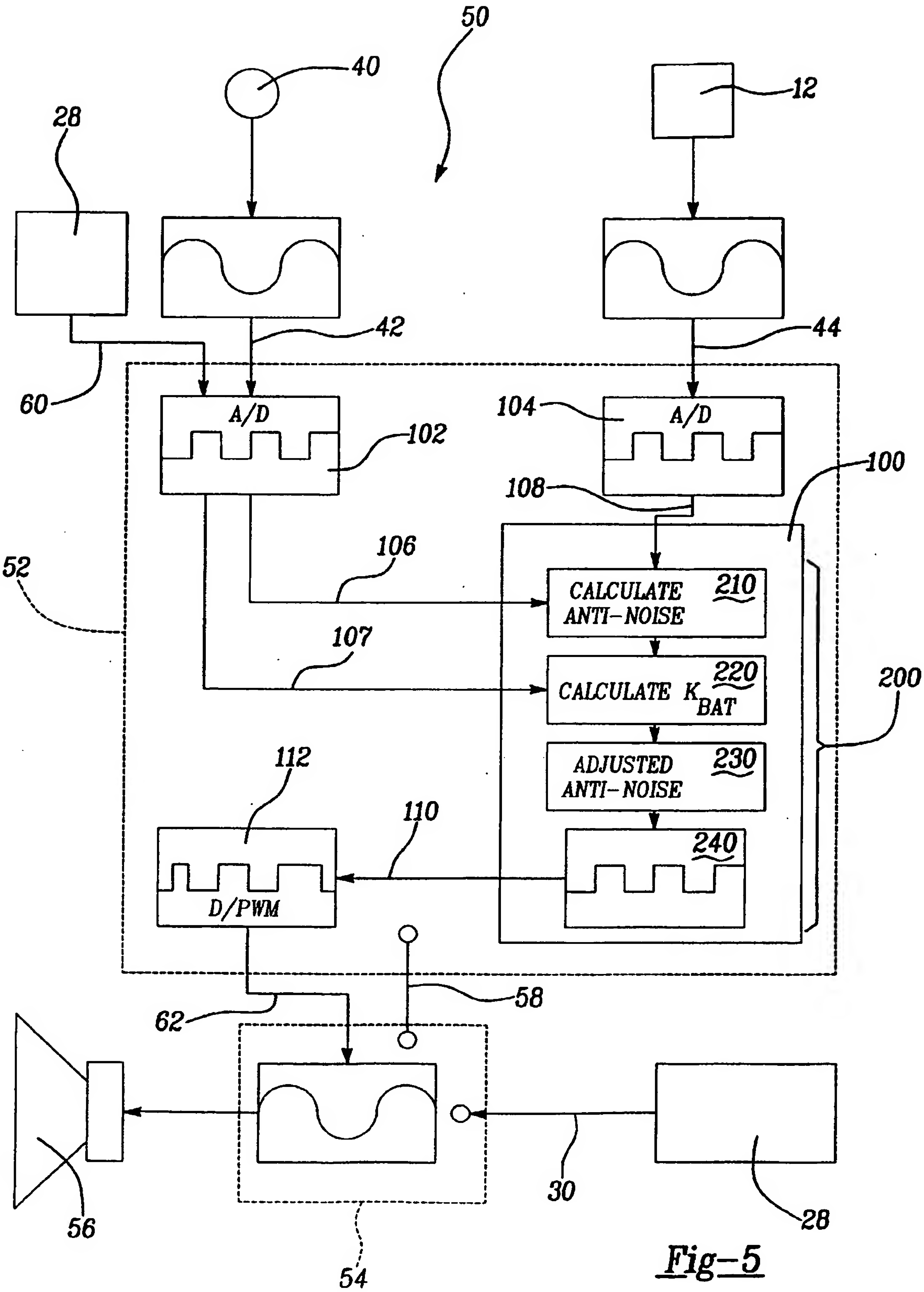

50
40
12
28
42
44
60
A/D
102
104
A/D
100
108
106
52
CALCULATE ANTI-NOISE
210
107
220
CALCULATE K_{BAT}
200
ADJUSTED ANTI-NOISE
230
112
110
240
D/PWM
58
62
56
30
28
54

Fig-5

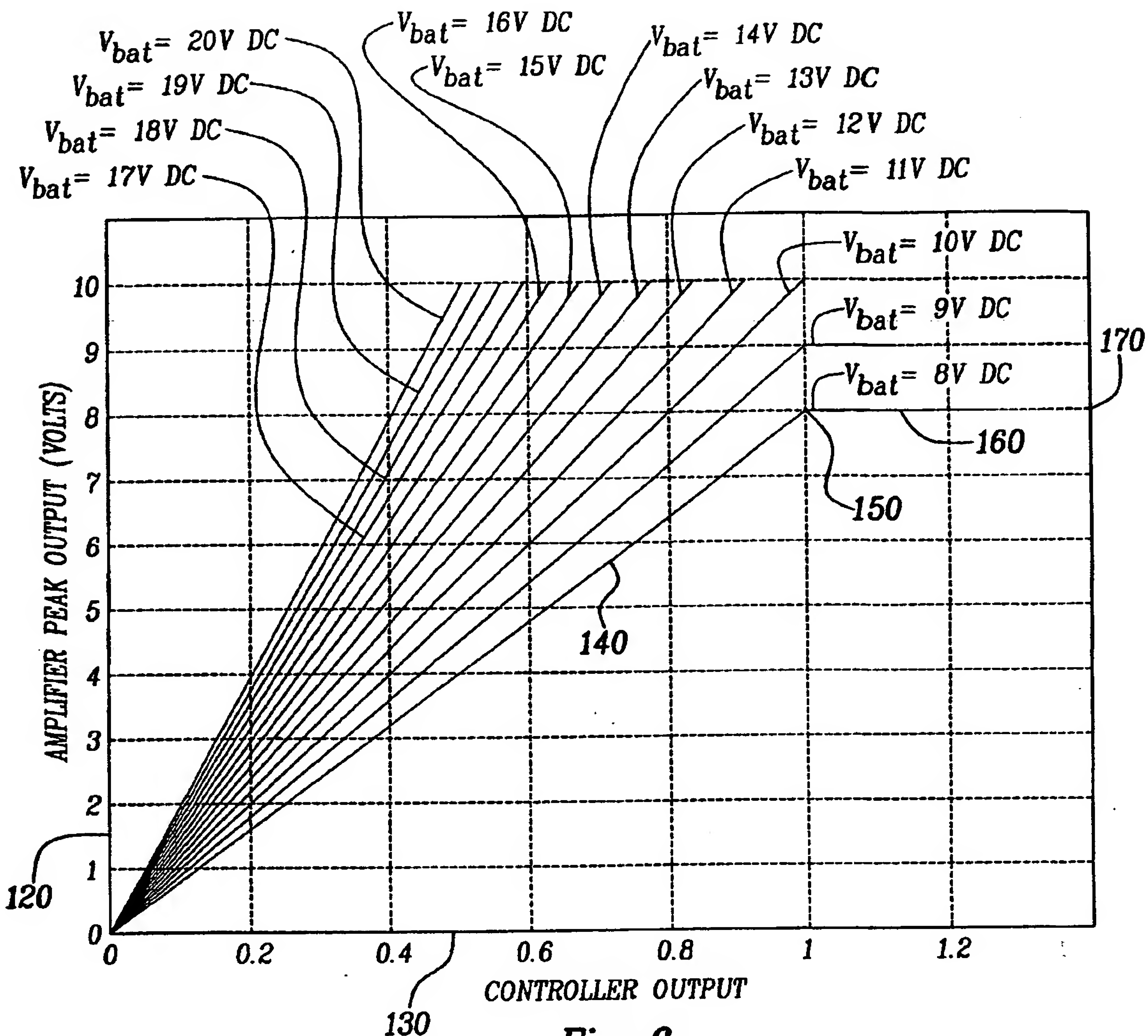

Vbat= 20V DC
Vbat= 19V DC
Vbat= 18V DC
Vbat= 17V DC
Vbat= 16V DC
Vbat= 15V DC
Vbat= 14V DC
Vbat= 13V DC
Vbat= 12V DC
Vbat= 11V DC
Vbat= 10V DC
Vbat= 9V DC
Vbat= 8V DC
170
160
150
140
120
130
AMPLIFIER PEAK OUTPUT (VOLTS)
CONTROLLER OUTPUT
0
1
2
3
4
5
6
7
8
9
10
0.2
0.4
0.6
0.8
1.2

Fig-6

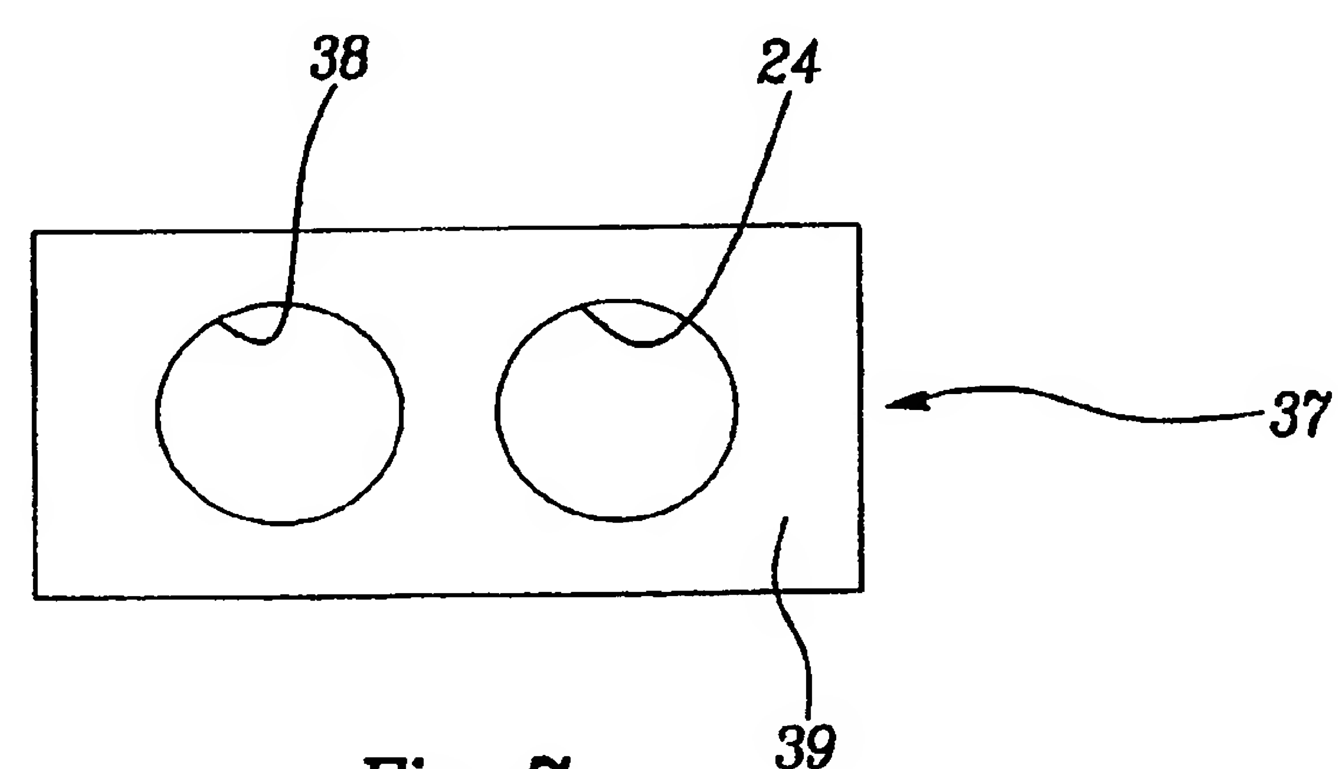

38
24
37
39

Fig-7